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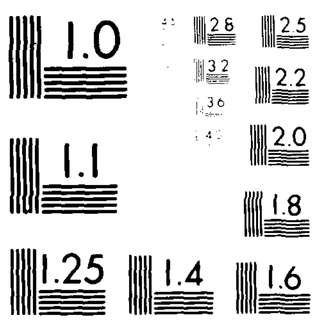

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ADVISORY GROUP FOR AEROSPACE RESEARCH & DEVELOPMENT

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AGARD ADVISORY REPORT No. 146

Technical Evaluation Report on the Fluid Dynamics Panel Symposium on Subsonic/Transonic Configuration/Aerodynamics

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9 AGARD Advisory Report No.146

6 TECHNICAL EVALUATION REPORT

on the

FLUID DYNAMICS PANEL SYMPOSIUM

on

SUBSONIC/TRANSONIC CONFIGURATION AERODYNAMICS

by

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1. INTRODUCTION

The AGARD Fluid Dynamics Panel held its spring symposium 1980 on "Subsonic/Transonic Configuration Aerodynamics" at the Hochschule der Bundeswehr München, Neubiberg, 5-7 May, 1980. The symposium has been prepared by a program committee whose members are: B. Laschka (co-chairman), H. Yoshihara (co-chairman), C.L. Bore, R.O. Dietz, B. Monnerie and B.M. Spee. The intention of the meeting was as indicated in the announcement:

> The requirement of improved performance of military combat and airlift aircraft requires not only highly refined point designs at specific flight conditions, but also mission design to maintain optimal performance over the flight spectrum; for instance, by variable geometry concepts. Of particular importance here is the aerodynamic design of the wing, fuselage, components of the empennage, external and conformal stores, fuselage and wing-mounted nacelle-pylons with their powered jet exhausts at subsonic and transonic Mach numbers such that each component achieves optimal performance under the influence of the other components. Here, not only must adverse interference effects be eliminated, but positive favorable interference must be sought. There have been great strides recently in the understanding of aerodynamic interference through more carefully conducted and highly diagnosed windtunnel tests, as well as by the availability of versatile computer codes and powerful computers. It will be the aim of the Symposium to report on these accomplishments. Vectored thrust in the context with V/STOL is excluded.

With this scope the meeting was a direct successor of the FDP-Symposium "Aerodynamic Interference" held in autumn 1970. At that time the solution of aerodynamic interference problems at subsonic and supersonic speed became feasible with the development of panel methods. This meeting concentrated on transonic speed with some view on special subsonic cases.

Within this meeting 28 papers have been given within the five sessions:

- prediction methods,
- weapons carriage,
- configuration optimization,
- powered jet interaction, and
- multicomponent interference.

About 180 participants attended the meeting.

2. THE SESSIONS

2.1 Prediction Methods

In this session three papers were presented which gave some insight into the state of the art of prediction methods. But also in the other sessions the development and examination of prediction methods has been dealt with to various extent. This will be commented within this context, too.

Prediction methods for configurations are either

- singularity methods for subsonic subcritical flow (panel-, vortex-lattice-, lifting-surface methods, etc.)

or

- flow-field methods for subsonic/transonic supercritical flow (finite difference-, finite element-, finite volume methods, etc.).

Both types of methods have been discussed at this meeting. In the centre of the discussion of this session was the treatment of transonic prediction methods for attached flow. The first paper given by E.M. Murman and J.E. Mercer (1) discussed a modification of the finite volume code of Jameson/Caughey (FLO27) to yield results for a wing in a windtunnel and a wing-body combination. The method is based on the full potential equation using a transformation of the physical space into a computational space. This is very effective as it enables to insert the boundary conditions in an accurate way. On the other hand the treatment of complex configurations becomes very difficult, since the transformation will become very intricate.

The comparison with experimental results shows that in both cases a good agreement with experiments can be achieved. The agreement is so excellent that the question arises whether there remains sufficient margin to accomodate the boundary layer effects. Since the theory used here is an inviscid one, there has to be some discrepancy which is not obvious especially in the wing-body case.

Paper 2 given by Y. Vigneron, O. Brocard, J. Bousquet and T. Lejal (2) gave a new approach to the transonic problem. On the basis of the variational principle which has been modified in the supercritical region a finite element method for wing-body combinations has been built up. The grid available seems adequate for this case, but the question arises whether the network possesses enough transparancy when dealing with complex geometries.

As to the implication of lift, a jump in the potential behind the wing is anticipated. The treatment of shocks is by shock-embedding technique - this requires a dense positioning of the grid points in the shock-region.

The third paper by G. Heckmann (3) also dealt with a finite element method used for the prediction

of the pressure distribution for a wing-fuselage-pylon-nacelle arrangement. In addition to this, experimental investigations in the windtunnel have been performed to verify the theoretical results.

The method based on the finite element approach via optimal control of Perrier and Périaux allows a very good representation of the flow-field by a grid, which follows all corners of the complicated configuration. The grid shown for such a complex case demonstrates quite clearly the versatility of this method and shows that this type of discretization is adequate. As to viscous effects some crude approach to the boundary layer is introduced. These theoretical investigations, which lead to an improved inlet for the nacelle, have been performed, before the experiments in the windtunnel were carried out.

Heckmann states that this theoretical study has shown good results and especially

- has provided results in a rather short time
- has achieved them with less cost than would have been necessary for an experimental optimization.

Now some comments on other papers which deal with transonic prediction methods shall be given. W. Schmidt gave in his survey-paper (9) some comments on transonic prediction methods. He showed that the transonic small perturbation equation (TSP) in the mass flux formulation can be used with reasonable success, when combining it with a full potential method for the last iteration steps. The TSP code suffers from its orthogonal grid system and hence the leading edge representation for wings is poor. This can be overcome by using the grid-embedding technique which highly improves the leading edge results and the shock resolution. In this survey Schmidt also noted the importance of viscous effects.

The high potential of TSP combined with grid-embedding-technique was shown by C.W. Boppe and P.V. Aidala (26) in their paper on complex configuration analysis at transonic speeds. The authors presented a finite difference method on the basis of an extended transonic small perturbation equation. Special feature of this method is the use of embedded fine meshes in special regions to obtain details of the flow. Thus more than 5000 netpoints can be located near the contour; this is more than the number of pivot-points generally used in a subsonic panel method. The method is combined with a geometry-generation program and a slender body correction is used to evolve the condition at the substitute boundary netpoints near the contour. A 2D Bradshaw type boundary-layer method is combined with the potential flow method. In this boundary-layer method some first order effects due to sweep are incorporated.

Boppe shows results of this method for a canard type fighter configuration, a transport aircraft configuration (KC141) and the space shuttle launch vehicle together with the space shuttle. These examples demonstrate quite clearly the validity and wide applicability of this method. In general good agreement can be achieved, although in critical regions as junctions, ducts and channels, certain effects occur which cannot be treated with the method described here.

As to transonic field methods another approach shall be discussed here which has been presented by G. Krenz and B. Ewald (12) on transonic wing technology. This finite difference method based on streamline coordinates is developed with the intention to treat arbitrary shapes and interference problems. The difficulty which had to be overcome was the rather high amount of computing time which has been shortened by using sectionwise 2D approach. The results given in the paper for the ONERA M6 wing show some derivations from experiment and from FLO22.

The results of different transonic prediction methods show that most of the methods ultimately with some restrictions give acceptable results.

After having discussed the transonic methods a short view shall be devoted to subsonic methods. Here a general standard has been achieved by the extensive use of 1st order panel- and vortex-lattice methods by aircraft-firms. Use of these methods is the state of the art and the main activities on these methods lies in further simplification of their use and further exploitation:

- W. Schmidt (9) gave some results as to automatic panel generation, which is a point of extreme importance, if panel methods but also other methods based on discretization shall be used as routines.

- R. Deslandes (6) gave an extension of the MBB-panel method for the evaluation of store-interference effect and store-release.

- J.M.J. Fray and J.W. Slooff (16) gave an extension of NLR-panel method due to thickness design of the wing and N.Voogt and J.Th. van der Kolk (25) have used this program framework for proper design of a subsonic transport aircraft wing.

- I.H. Rettie (27) briefly described the panel- and vortex-lattice methods available at BOEING and gave as examples different overwing-nacelle- and winglet designs.

No paper has been given on higher order panel methods although the shortcomings of the generally used first order panel methods is obvious. Work under way at BOEING, DOUGLAS, DORNIER and other places shows that there is more activity than could be seen at this meeting.

Another important feature is the availability of prediction methods for concentrated vortex flow over small aspect ratio wings. As to this topic the meeting did not give any information as to the theoretical side.

2.2 Weapons Carriage

The next session was devoted to weapons installation and the problems related to it. Aerodynamics of store-interference are extremely complicated due to the variety of corners, ducts and channels where strong

viscous-inviscid interaction and large areas of separated flow occur. Key aerodynamic problems are drag minimization and improved prediction of store trajectories.

AGARD has been very active in the past in this area. One of the most important activities in the last years was a Working Group on the subject "Drag and Other Aerodynamic Effects of External Store" *). The first two papers of this session give some important results of this activity.

The paper given by C.L. Bore (4) on "Increasing the value of airforces by improving external store configurations" brought the auditorium very directly to a key point of all technological improvement: How can the value of airforces be increased for the same or less money? Of course, aerodynamicists propose improvements in the design and installation of weapons. But is it indeed cost-effective to improve the aerodynamic quality? By using criteria for the effectiveness of weapons as war-load transport rate, availability in war-time, target killing effectiveness, Bore defines an overall value which allows him to assess the efficiency of improvements. His conclusions are that low drag leads to greatly increased survivability and better predictable store trajectory. This will improve the target killing effectiveness.

The benefits obtained therefore are especially improvement of the effectiveness and availability of airforces whereas direct cost-savings tend to be small compared with this. Nevertheless qualitative improvements may lead to a quantitative reduction of weapons systems, and this also reduces costs.

The next paper by A.B. Haines (5) led back to aerodynamics and discussed the prospects of minimizing external store drag. This survey paper examines a number of aspects of store installations. Special attention is devoted to multiple carriage and to favorable interference sometimes connected with it. Haines shows several examples which demonstrate quite clearly that different arrangements of stores may improve the drag behaviour drastically. An example typical for this shows that a special arrangement with 20 bombs has a lower drag at transonic speed than an arrangement with 5 bombs in the same region beneath the fuselage. Main reason for this improvement is a better area ruling.

Another favorable position of slender stores is the wing-tip. In this case the store has a favorable influence on the induced drag. A further method already tested to large extent is conformal carriage. Here the stores are mounted as close as possible to the aircraft. By doing this, good streamlining and minimal wetted area can be achieved. Another point Haines stresses is the fact that positioning of a store is much more difficult on a wing with supercritical performance. Here shocks may occur where they are not expected. Therefore, for new combat aircraft the weapons carriage should be integrated into the design process from the beginning.

Whereas the paper just commented presented a lot of drag data from windtunnel and flight, the next paper by R. Deslandes (6) gave a mixed experimental-analytical approach to the evaluation of store trajectories at subsonic and transonic speeds. Basic method used for the perturbation flow-field near the aircraft is the subsonic panel method which can be used for quasi-steady calculations, when ΔMa for carrier and weapon does not exceed 0.3. Since this is the case for most of the weapons in the near field of the carrier a steady method applied at different time-steps can be combined with a scheme for the solution of the equation of motion in order to get the store trajectory. Optionally the perturbed flow-field near the carrier can also be fed into the program by using flow-field measurements from windtunnel instead of theoretical results. Deslandes showed a number of examples comparing windtunnel experiment with numerical results.

The last paper of this session was given by S.S. Stahara (8) on transonic configurations with external stores. An extensive experimental/theoretical program has been performed whose aim is to develop prediction methods for three-dimensional transonic flow fields around aircraft configurations and its influence on external stores. Within this program detailed pressure measurements on wing, fuselage and external stores as well as forces and moments have been measured for an idealized F-16 model. Beyond this, flow field measurements have been performed in order to have a generic data base for realistic three-dimensional configurations at transonic speeds.

The theoretical work shows quite clearly that neither transonic equivalence rule nor pure linear evaluation by panel methods are sufficient for an adequate representation of the flow behaviour. Stahara finally proposes a 3D panel method, where the essential 3D nonlinear effects, which are primarily due to the wing, are evaluated by 3D TSP for the wing alone. This brings satisfactory results for sidewash and upwash as well as for the velocity in streamwise direction. Shortcomings of the method are its inability of predicting characteristics in high-gradient regions and store-generated effects.

The experimental results and the different theoretical approaches tried with less or more success show the high complexity of the transonic flow problem of wing-body combinations with stores. May be that the TSP method with grid-embedding (see Boppe (26)) is the best available inviscid theoretical approach to this problem, but it has to be considered that

- for a trajectory or even an optimization of the store-location these calculations have to be repeated so often, that its practical use for design purpose is questionable at the moment
- viscous effects are totally neclected, whereas especially in the transonic region, there is a significant influence.

Looking at the session as whole, it must be stated that the papers given here only represent a small part of the overall effort on external stores. Nevertheless the presentation of the main results of the AGARD Working Group as well as the two additional papers gave an elucidating insight into the performance problems.

Perhaps the program committee would have done better to omit these problems within the scope of the symposium. The rather scarce discussion after the presentations also gave an indication for this. Never-

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theless this is an important problem which deals with very complicated aerodynamics on the experimental and theoretical side. It deserves a meeting that goes beyond what could be discussed at Neubiberg.

2.3 Configuration Optimization

The session on configuration optimization consisted of three main parts:

- some general papers on aircraft design, especially devoted to theoretical methods (9, 10)
- aspects of optimal performance of subsonic transport or components (11, 12, 13, 16, 25, 27)
- aspects of optimal performance of combat aircraft or components (14, 22, 15, 21).

The first presentation of this session was by W. Schmidt (9) who gave a survey-paper on aerodynamic subsonic/transonic aircraft design studies by numerical methods. This contribution brings an overview on prediction methods and design methods available for subsonic/transonic performance and some applications of these methods combined with experimental results. Schmidt states that considerable progress has been made using computational fluid dynamics in the aircraft design process. Subsonic panel- and vortex-lattice methods, transonic finite difference and finite volume combined with some boundary-layer evaluation on wings give a substantial insight into the flow behaviour and into the design process. Schmidt also comments on the shortcomings and although much progress has already been achieved, there are still open

- appropriate overall boundary-layer consideration
- lacking knowledge as to separated flow.

Besides this much work has to be invested to get a better general applicability of the codes. Here especially automatic mesh-generation and speed-up of the codes to get reasonable computer times is necessary. With this ability, computers will not offset windtunnels, but reduce the effort of experimental investigations.

The next paper by H. Sobieczky (10) gave a very interesting aspect to transonic wing design. Sobieczky postulates that a wing having a shock-free or near shock-free flow on its surface is the optimum choice for transonic performance. To achieve this, he has developed an ingenious method to transfer any given airfoil or wing with a supersonic flow region with a shock into a shockless airfoil by redesigning the contour beneath the supersonic area. The idea how to do this is rather simple but very effective. First the flow field is calculated with a purely subsonic method. At field points where the local Mach number exceeds one, the density is kept constant to provide an elliptic continuation of the basic equations. The sonic line then is the starting point for a proper evaluation of the embedded supersonic flow field, which leads to a modified contour beneath the supersonic range.

An examination of the airfoils and wings designed this way shows that not in all cases a fully shock-free design condition can be achieved. Nevertheless the idea and the approach are convincing since they give the possibility to convert any airfoil or wing with embedded supersonic region into a nearly shock-free design. In addition the number of shock-free solutions is unlimited since each choice of the fictitious gas yields a different solution. This approach should be tested experimentally which has not been done up to now.

The next papers discussed in this session are devoted to the design and optimization of subsonic transport configurations or components of it. In the first paper of this series J.A. Jupp (11) gives an interesting insight into the aerodynamic development of the A310 wing including interference effects. It is remarkable to note that the design of this wing has been done primarily by theoretical methods, thus achieving a major improvement against A300 by supercritical design. Indeed the experimental verification brought no major change to the theoretical design. Another positive aspect is that theoretical methods helped to speed up the whole design process. So more effort could be devoted to the interference problems which occurred integrating the other components of the wing which was done by a "trial and error" procedure in the windtunnel. This way the wing-root fairings, the flap-support and the nacelle-pylon-wing arrangement have been optimized.

The author furthermore discusses the reduction of the nose-down pitching moment of the highly loaded wing by bringing more air-loading to the inner part of the wing. This causes an induced drag penalty but reduces the tail-size. For long-range cruise a better overall L/D is achieved.

Another wing designed and optimized for a specification which fits the A310 requirements was presented by G. Krenz and B. Ewald (12) and G. Anders, A. Giacchetto and A. Gravelle (29). This wing has been designed by theoretical methods having special care for off-design and linear wing-lofting. Furthermore a high wing thickness at the root and the kink should be achieved with a profile having an as high as possible spar at the rear end to reduce structural weight and increase storage capacity. Starting point of the design process was a well-designed supercritical airfoil thoroughly tested up to Reynolds numbers of $13 \cdot 10^6$. Small and large scale models have been built and tested in different windtunnels. An interesting feature is the comparison of full model results at low Reynolds number versus half model results with moderate Reynolds number. These results and other interference aspects will be discussed within chapter 2.5.

This paper furthermore gave a survey on the activities on transonic wing technology for transport aircraft in Germany including some aspects as to future work.

The paper presented by G. Redeker, N. Schmidt and R. Müller (13) dealt with a similar exercise: design and verification of a transonic wing for a transport aircraft. The authors followed the classical way

- theoretical design and optimization of a 2D airfoil with a substantial amount of supercritical flow and rear loading
- experimental verification of the 2D-design

- incorporation of this basic airfoil into the sheared wing part. Evaluation of twist by the constraints of minimum drag and nearly straight isobars on the upper surface

- experimental verification of the 3D wing.

In the whole process the authors obviously were aware of the constraints necessary for such a process. The airfoil as well as the wing have attractive performance. This could be verified in windtunnel.

Main results of this exercise are

- for high aspect ratio wings ($\Lambda \approx 10$) and moderate sweep ($\varphi < 30^0$) the classical approach of first designing an airfoil and then incorporating it into a wing is well suited

- the airfoil characteristics dominate the flow on the wing to a large extent

- computational methods are well-suited for the design of high performance wings

- some discrepancies are found when comparing 3D TSP results with experiment.

With respect to the A300 the average wing thickness could be increased about 15%, the leading edge sweep reduced by 10% for a cruise lift of $c_L = 0.5$. Unfortunately the results are only given for the rather small Reynolds number of $1.9 \cdot 10^6$.

The paper given by J.M.J. Fray and J.W. Slooff (16) treats the general problem of thick wing design. As many design processes, this is a multivariate problem where there are a great number of possible solutions. Art of the aerodynamicist is now to find out the solution which fits best with different requirements. The authors describe a panel-type method for the design of a wing with given pressure distribution in subsonic flow. A fuselage with prescribed geometry can be included. The method is formulated in such a way that certain geometric constraints as wing-twist, thickness distribution, leading edge radius, and trailing edge angle can be taken into account. Thus the designer may control the iteration procedure in order to decide what penalties can be allowed to satisfy certain contraints. Some results show the effectiveness of this method.

From the theoretical basis, this method is not valid for supercritical flow, but a modification to this has already been done and used, as can be seen from the paper by N. Voogt and J.Th. van der Kolk (25) on a design study for the root part of a transonic wing-body combination of aspect ratio 8. First step for the wing-design presented here is the use of 2D methods – in this case hodograph method – for the design of an appropriate 2D airfoil. The pressure distribution of this airfoil then is evaluated by 2D subsonic panel method, which leads to reference values. This target is used to generate the 3D wing by straight isobars or other constraints with the method described in (16).

A first straight forward use of the program shows that the thickness of the wing-root reduced from 10% as a first guess down to 4%. After imposing additional constraints a better solution could be achieved. Further studies have been performed as to the influence of leading edge extension and body fairings. The investigations show that both are powerful means and can be predicted with the method presented. Experimental results back-up the effectiveness although viscous effects have not been taken into account in the theoretical approach. The ultimate wing-design satisfies the very ambitious design goal for cruise. Unfortunatel/ no results are given for the off-design case. The authors argued in the discussion that no adverse 3D effects or buffet penalties occur.

Another paper given in the session on "Multicomponent Interference" has to be mentioned in this context. This is the paper by I.H. Rettie (27) who described the aerodynamic optimization of an overwing nacelle-wing arrangement and an overall optimization of a winglet for a given aircraft. As in the preceding papers both designs have been done with subsonic panel method thus giving a good example for the standard achieved in the use of such methods for the optimization of configurations.

The main problem of integrating an overwing nacelle is the necessity to have a favorable or at least zero interference with the supercritical flow on the upper surface of the wing for high subsonic cruise. Pilot-investigations have shown that favorable interference can be achieved. Guideline for the theoretical studies within this paper is not to perturbe excessively the flow field of the clean wing by a proper alignment of inboard and outboard junction. Since the authors have available a subsonic theory, the design has been done for purely subcritical cases. The results show very clearly where first supercritical regions and shocks can be expected. A proper design is given for the two-engine airplane. Another example for a four-engine airplane exhibits larger difficulties especially due to the very high section lift between inboard and outboard engine, but this should be no principal failure of this engine-arrangement. In context with this arrangement, figure 12 shows the sectional lift which tends to zero at the wing-root. This must be a mistake.

The second topic of this paper is devoted to proper winglet-design. The author of the paper points out the favorable effects of winglets. These are endplate effect, mutual favorable interference of wing and winglet as to induced velocities and minor additional bending moment than for a comparable span extension. A mere aerodynamic optimization of the tip form will always lead to a span extension. Due to structural limits a winglet may be favorable.

In course of the investigation, parameter-studies have been performed to find the optimum form for the winglets. Parameters have been aspect ratio, winglet area and cant angle. Furthermore the additional structural weight and the overall performance of the airplane have been looked at. The winglet profile, camber and twist have been optimized by theoretical methods. These investigations have been done for two airplanes, the YC-14 and the KC-135. Windtunnel investigations at high speed and low speed show that the promised gain can be verified.

Finally it can be said that winglets are a powerful means to improve efficiency of existing aircraft when only minor modifications in the wing structure are allowed.

The following papers dealt with the aerodynamic optimization of fighter type configurations. I adopt here what Atraghji said – with some modification – as to the key problems. The main features are:

- good cruise performance = low drag at cruise lift
- good manoeuvre capabilities = high useful lift without severe buffet
- good take off and landing performance = high L/D at moderate c_L, high lift for landing
- good handling qualities throughout the flight envelope = attached or controlled separated flow
- simplicity of design = usability in service
- low structural weight = higher payload.

E. Atraghji, L. Thornqvist and L. Torngren (14) compared in their paper two wings ($\Lambda = 4$, $\varphi = 27^o$) for a subsonic combat aircraft which have two different design philosophies. One was designed for cruise condition having a variable deflection leading edge capability, the other with fixed nose droop, a compromise for all flight conditions. The windtunnel investigations at rather high Reynolds number (about $12 \cdot 10^6$ and for some cases up to $18 \cdot 10^6$) show that it is possible to find a good fixed nose droop compromise for all flight conditions. This nose droop wing has only a small penalty at higher Mach number cruise but for the rest it is superior to the wing with leading edge device.

The design of this nose droop wing was described in some detail by G. Drougge (22). This study again shows that subsonic and transonic methods for prediction and design can be used in an effective way for the design of a transonic wing. Drougge looks in detail into the compromise one has to find between high lift for low speed as well as manoeuvre conditions and transonic low drag. First attempt using nose droop leads to high cruise drag. Inspection of the pressure distribution, especially the evaluation of the sectional drag force shows that the high drag results from the outboard region. A reduction of nose droop in this region leads to a better transonic performance while the good high lift behaviour is sustained.

The paper by D.R. Holt and B. Probert (15) dealt with some particular configuration effects on a thin supercritical variable camber wing. These different effects are: variable camber, aeroelastic distortion and productionizing of the wing.

As to variable camber the authors first describe basic 2D work on thin airfoils with flaps. The design of the basic airfoil is done for the high "g" manoeuvre case. This leads to a supercritical airfoil with nose droop and rear loading. The "1g" case is achieved by negative flap deflection.

This is a very interesting approach since here the most critical case is matched by a proper design while the usual way of designing manoeuvre flaps proceeds by first designing the airfoil for 1g and then achieving higher "g" performance by positive flap setting.

Based on this airfoil philosophy a wing with variable camber has been designed (AR = 3.3, $\varphi_{LE} = 42^o$, $\lambda = 0.3$). The availability of fullspan variable flap setting gives a high performance flexibility to the wing, of course within the limits of the basic airfoil. The study shows that variable camber is a powerful tool to match different design goals in the transonic region.

It shows furthermore that in the transonic manoeuvre case extreme aeroelastic deformations occur. So the washout of a thin wing goes up to 10^o, a deformation which has to be taken into account in the design process from the beginning.

The last aspect of the paper is devoted to the subject of ease of fabrication. The wing shape investigations show that a reduction to three and even two control sections is feasible without losing too much efficiency.

The last paper on combat aircraft wing design and characteristics was by T.M. Weeks, G.C. Uhuad and R.A. Large (21) on the comparison of a forward swept wing with an equivalent swept back wing. Advantages of a forward swept wing can be:

- reduced induced drag over a great part of the flight envelope
- higher c_{Lmax}
- reduced wave-drag at transonic and low supersonic Mach numbers
- reduced wing-root bending moment
- improved efficiency of aileron.

The swept forward and swept back wing investigated have the same wing area, aspect ratio, taper ratio and the same sweep of shock-location ($\varphi = 40^o$). This leads to wings which have a leading edge sweep of -28^o and 48^o. The results show that the forward swept wing has got

- a reduced airfoil drag due to reduced leading-edge sweep which induced a higher leading edge suction
- a reduced wing-root bending moment due to a more inboard centre of load on a wing-half, which allows a higher aspect-ratio and with it a smaller induced drag
- an extreme sensitivity to wing-height position when combining the wing with a fuselage of circular cross-section
- for all Mach numbers a somewhat higher non-lift dependant drag.

All the trends give some interesting feature of a swept forward wing design. An overall estimation cannot be drawn since it is doubtful whether the wings compared are "equivalent". Furthermore the proper selection of the cross sections for the fuselage is an important point, since the highly loaded inner part of the wing is much effected by the upwash of the fuselage. In addition it is astonishing to see what high amount of twist has been applied. Theory tells that moderate forward sweep combined with proper planform-taper without using any twist leads to a spanwise load distribution which is nearly elliptic. This is one of the main advantages of forward swept wings which should not be surrendered.

2.4 Powered Jet Interaction

Four papers were given within this session. In fact the subject of these papers was the specific problem of a powered jet interacting with a wing. The more general aspects of powered jet interference will be discussed in a FDP-specialist meeting in spring, 1981 in Toulouse.

Two papers were devoted to fundamental aspects of a jet interacting with a wing, while the two other papers were directed more towards parameter studies for specific design options. At first the more fundament·l aspects may be considered.

The paper given by R.A. Sawyer and M.P. Metcalfe (18) *a jet-wing interference for an overwing engine* configuration is a study which has been conducted to find out whether a moderate bypass ratio engine mounted on the wing of the HS 748 will have favorable effects. Furthermore this study shows some fundamental aspects. A two-dimensional model has been used blown over by a cold jet in its structure typical for a moderate bypass engine. The investigators found that increments in lift occured combined with some increase in wing drag. Detailed patterns of the pressure decrement on the upper surface are presented which give an insight in the extension of the jet influence. This is accompanied by smoke visualization of the jet. In addition a theoretical approach is given, where the entrainment of the jet is simulated by a sink-distribution on the axis and the curvature by horseshoe vortices, whose strength is determined by the curvature of the jet. The investigators found out that the main suction effect of the jet on a wing is due to curvature of the jet and not due to the entrainment. Theoretical calculations with the horseshoe vortex-lattice show a good agreement with experimental results. Although good agreement is achieved some doubts may be expressed with respect to the completeness of the theoretical model used and the conclusions drawn.

A study which is similar to the preceding paper is the work given by P. Levart (20) on an experimental investigation of the interaction between a powered nacelle and a wing. Apart from the fact that a sheared wing is used instead of a straight one the basic set-up is the same. A number of parameters have been investigated as nacelle position, Mach number varying from 0.3 to 0.8, with and without pylon and three different types of nacelles. Extensive pressure plots have been performed; the author gives some reference cases and concentrates on the presentation of the change of sectional and overall values, which have been evaluated from pressure plots and wakes measurements. The work will provide a comprehensive set of data when concluded.

The next two papers dealt with jet interference on combat aircraft wings

- one paper on internally blown flaps (IBF) especially looking after supercirculation effects
- the other on blowing parallel to concentrated vortices in order to form or to stabilize vortex flow.

The paper presented by A. Vint (17) dealt with the first topic. The basic idea of this paper is to look at the possibilities of internally blown flaps for a fighter type aircraft. Therefore a simple and rapid estimation method is needed. Based on the work of Maskell and Spence a method is presented which allows the prediction of lift, drag and pitching moment. The comparison of results achieved with this method with experimental findings shows reasonable agreement. This method then is used to examine the aircraft performance having IBF with supercirculation. The study shows that use of supercirculation is a realistic possibility to get higher performance in the low speed range. The very high nose-down moment generally known for blown flaps configurations can be overcome by using canard configurations, which of course have a negative stability at least at high c_L. Furthermore the necessity to bleed the engine's efflux partially on the flaps will require alternative engine positions and nozzle shapes. The author claims that substantial improvements in low speed low altitude manoeuvre - which occurs in the last stage of dog-fight can be achieved with this technique.

The next paper is aimed in the same direction. W.H. Staudacher (19) shows in his paper that a stable vortex system on the wing can be achieved by concentrated spanwise blowing either from the wing-root or from an outboard station. The idea of this technique is, to blow high energy air parallel to the core of a bursting or just burst vortex in order to renew a concentrated form of the vortex. Staudacher shows that this method brings increased maximum lift, reduces the drag level at high angles of attack and improves roll control. Furthermore using this technique on the surface of controls increases efficiency and improves spin prevention or recovery. It can also be used for the control of vortices on forebodies.

One characteristic result of the experimental investigations is a parameter study as to chordwise position of the nozzle, nozzle height above wing and blowing direction. It turned out, that the maximum efficiency can be achieved at a blowing position of 40% root-chord with a jet direction parallel to the leading edge. The nozzle height is a not very sensitive parameter. The maximum efficiency which could be achieved was $\Delta c_{L_{max}}/c_\mu = 5.2$. Blowing from a nozzle position on the wing brings no improvement. Hence, the most simple system is the most efficient one.

This method of augmenting lift by blowing parallel to concentrated vortices seems to be an effective one, but its efficiency is restricted to low speed. Furthermore since the amount of compressed air necessary to control the flow exceeds the possibility of the engine, an auxiliary power unit for air supply is inevitable.

Another basic point must be stressed. Up to now it seems not to be quite clear what are the physics that govern this behaviour. General ideas are expressed, but more clarification is needed.

2.5 Multicomponent Interference

The last session of this symposium was devoted to multicomponent interference. Within this session the mutual aerodynamic interference of different parts of the aircraft were examined. Mutual interference of several parts of the aircraft have already been pointed out in other sessions as

- store interference in the weapons carriage session
- powered jet interaction in the so called session
- wing-body interference in the session on configuration optimization and prediction methods.

So the points discussed here are only the remaining topics as wing-canard, wing-strake, inlet external drag and some special topics.

The first two papers of this session have already been discussed within the session configuration optimization. The first paper to be discussed in this context is that of Y. Brocard and V. Schmitt (23) on the aerodynamic interaction between a close-coupled canard and a swept back wing in transonic flow. This experimental investigation which comprises force- and pressure-measurements as well as flow visualization gives a good insight in the flow behaviour of a swept wing at low and high angles of attack in the subsonic and transonic region without and with canard. The first part of the paper is devoted to compressibility effects and is for the wing alone. The authors show that compressibility has a marked effect on lift curve slope at low angles of attack and on vortex onset. It is furthermore shown that compressibility leads to more abrupt changes in lift and pitching moment due to vortex break-down appearing at the wing. At $M = 1.2$ a shock appears in the reverse flow on the wing and behind it a stable secondary vortex.

The addition of a close-coupled canard leads to additional effects which are in its basic behaviour similar to incompressible flow, namely the reduction of lift curve slope and connected with it the attenuation of vortex development due to the downwash of the canard. The concentrated vortices on the wing are pressed down by the downwash of the canard. Furthermore the canard diminishes the discontinuities due to vortex break-down arrival but two other discontinuities occur at higher angle of attack which are due to the bursting of the secondary vortex and the total breakdown of the concentrated vortex system. Nevertheless there still exists an organized structure due to a large burst vortex.

In connection with this paper two contributions of the symposium should be reviewed again. These are the papers by Staudacher (19) and Holt and Probert (15), where wings with strakes are also discussed.

Staudacher (19) examined in his paper the performance gains which could be achieved by a separated stable vortex system. Basic wing is a medium aspect ratio moderately swept trapezoidal wing with stable characteristics. Strakes of various form have been attached to this wing. Staudacher finds that optimum leading edge sweep of a strake is $\varphi = 75^{o}$ and optimum strake area approximately 10% of the total wing area. Such a strake increases maximum lift up to 80%, but this decreases drastically when the Mach number approaches 1. Further advantages of strakes are

- lower level of induced drag at high angle of attack
- higher usable lift especially as to buffet and rudder efficiency
- improvement of the dynamic behaviour.

An important point Staudacher stresses is the possibility of controlling the concentrated vortex by a leading edge spoiler. These investigations show promising results.

The third paper in which vortex flow was treated is that of Holt and Probert (16). They describe the design process and the performance of two different strakes added to a moderate aspect ratio wing with leading edge sweep of 45^{o}. The results show that the strakes chosen improve high angle of attack performance. At high Mach numbers ($M = 0.9$) marked discontinuities obviously due to flow break-down on the outer wing followed by break-down of the vortex can be seen.

Of course, the papers presented at this meeting on concentrated vortex-flow form only a small part of the whole game. Nevertheless the general situation is as Staudacher mentioned in his paper: "The overall effects of strakes on manoeuvre performance and flying qualities are well known and (less well) understood meanwhile". I would like to stress this "less well" since the understanding of the phenomenology is the basis for any reasonable theoretical approach.

The next paper by D. Treadgold and K.H. Wilson (24) presented three interference effects of combat aircraft wings. These are viscous interactions, aeroelasticity, and interference of the fuselage. As to viscous interaction some theoretical results with RAE TSP method combined with 3D boundary-layer calculations using an integral-method are shown. This program set also allows the incorporation of structural deformations based on calculated loads on the wing. In order to find out the influence of aeroelasticity a composite windtunnel model has been built to simulate aeroelastic deformations in the windtunnel. This simulation is not precise but it gives an insight into the problems that occur. Measurements on a typical fighter type wing ($\varphi = 42^{o}$, AR = 3.3) show that for Ma = 0.8 and $c_L = 0.8$ the change in incidence at the tip is about 7^{o}.

The third topic of this paper is wing-body interference especially the influence of different fairings. Treadgold shows that slightly varying fairings have a drastic influence on the drag of the configuration. It is interesting to see that this additional drag or improvement in drag behaviour does not occur on the fairings but on the wing. The pressure distribution changes drastically with different fairings. The authors also show up the increasing capability of computer methods in transonic flow for this case. Some pilot investigations show that the drag reduction effect of fairings can be predicted by transonic theory although the real pressure distribution of the wing is not predicted very well.

The last paper on interference problems of fighter type aircraft was given by O.J. MacMillan,

E.W. Perkins and S.C. Perkins Jr. (28) on a data base for the prediction of inlet external drag. The authors have studied the literature on this subject and have identified, categorized and evaluated the suitability of prediction methods and experimental data for preliminary design. Several methods have been identified and compared with experimental data. The general findings are that most methods for preliminary design are semiempirical and are valid within the scope of the experimental data, they have been derived from. Purely theoretical methods based on the solution of the potential-equation or the Euler-equations need large computers and long running time to achieve satisfactory agreement, while their usefulness is limited for preliminary design.

The last paper of the meeting again dealt with interference problems of subsonic transport aircraft. G. Anders, A. Giacchetto and A. Gravelle (29) gave a survey on the philosophy and experimental performance of a large scale transport aircraft model. The reason for using a 4.5 m half-span model is to achieve not only a high Reynolds number, but also to get good information on several interference aspects which cannot be obtained with smaller models. The paper describes in detail the potential of large scale models and comments on the difficulties connected with it. The main points which can be seen from these investigations are influence of Reynolds number and half-model versus full model, influence of a nacelle and influence of disturbances on the wing.

The authors only give preliminary results since the data achieved have not yet been evaluated totally. Unfortunately the effects of Reynolds number and full resp. half-model cannot be separated. Furthermore the half-model shows a large drag-creep which is not explained by the authors and which may be attributed to windtunnel wall effects. In the discussion it was pointed out that due to lacking suction on the fuselage of the half-model the overall drag may rise when using this technique. A further interesting point is the additional drag arising from contour disturbances. Here it is important to have defined steps which should exceed the laminar sublayer. So a slat excrescence of 3 mm (wing reference chord approx. 1 m) at 15% behind the leading edge on the upper surface leads to a drag increase of about 5% for the overall wing-body configuration. The second part of this paper describes the test set-up and first results for unsteady measurements.

5. CONCLUSIONS

The symposium has yielded much information on subsonic/transonic configuration aerodynamics. Nevertheless this subject generally includes more than has been presented at this symposium. If all these points would have been treated all participants would not only have to stay until Friday, as H. Yoshihara commented during the Round Table Discussion but indeed another week. So several points had to be omitted since they have been treated in past AGARD-symposia as

- "High Angle of Attack Aerodynamics" especially dealing with concentrated vortex flow, in autumn 1978 at Sandefjord
- "Aerodynamics of Controls" in spring 1979 at Naples
- "Computer as Tool for Aircraft Design" in autumn 1979 at Neubiberg (FMP)

or will be treated in future symposia as

- "Computation of Viscid/Inviscid Interaction" in autumn 1980 at Colorado Springs
- "Power Plant Installation" in spring 1981 at Toulouse.

So this meeting could only give limited information. Nevertheless conclusions will be drawn with an eye on what is going on beyond what we heard at this meeting. The conclusions will be given for three topics in the sequence:

- Computational Fluid Dynamics
- Interference Aspects
- Optimization.

The chapter conclusions will be ended by a section on some additional general remarks.

5.1 Computational Fluid Dynamics

A major outcome of this conference is the fact, that theory has become a powerful tool to develop and optimize basic configurations. As to prediction methods and furthermore the state of the art of computational fluid dynamics the following conclusions may be drawn:

For subsonic attached flow panel methods and vortex-lattice methods are in current use for prediction and design for complex configurations in aircraft-industry. Several examples for wing-body combinations and interference between wing and nacelle, winglet, fairing etc. have been shown. Most of these investigations have been done without consideration of boundary-layer effects but there are also results which include them. The main problems still open are

- geometry generation and automatic panel generation
- development and introduction of higher order panel methods
- taking into account properly viscous effects
- treatment of the Kutta-condition on bodies
- proper incorporation of jets.

As to transonic attached flow much progress has been achieved in the last years. Methods on the basis of TSP, potential-equation or Euler-equations have been developed using different finite approximations.

In general these methods now have achieved a status of being used for prediction and design as standard methods in industry. This has been shown quite clearly by Boppe, who gave a set of examples for complex configurations. Also here some first consideration of viscous effects has been incorporated. Nevertheless there are open problems to be solved as:

- proper and automatic mesh generation
- higher order discretization
- proper introduction of boundary-conditions
- incorporating viscous effects by 3D boundary-layer evaluation
- shock-boundary-layer interference
- treatment of Kutta-condition on highly loaded wings and bodies
- proper evaluation of drag
- incorporation of jets.

With regard to separated flow no major contribution has been given at this meeting. Theoretical methods for concentrated vortex flow, which is of special importance for fighter type aircraft, are available for simple configurations as delta-wings. Vortex onset and vortex break-down are still far from being incorporated in these methods in a proper way.

Dead air separated flow is highly unsteady and dominates the performance boundaries of aircraft given by c_{Lmax}, drag-rise, buffet etc. Some empirical and a few theoretical approaches are known, but have not been presented at this meeting.

The treatment of separated flow can be done in two ways, namely by

- hybrid-methods based on potential-flow plus boundary-layer plus some empirical modelling of separated areas. In general this approach is only valid for a limited range of application
- solution of the Navier-Stokes-equations but this is a long-term aim. Nevertheless it has to be stated, that the solution of Navier-Stokes-equations is not so far from being used for actual prediction work as can be seen from flutter-investigations done at NASA-Ames.

A further step forward in providing powerful data from theoretical approaches is the coupling of aerodynamic methods with methods of other disciplines. So the coupling of aerodynamic prediction methods with prediction methods for the static elastic deformation of wings gives an insight in the realistic behaviour of aircraft and windtunnel model. This is of special importance for combat aircraft since in manoeuvre flight, deformations may lead to a torsion of tip which lies in the region of 10^{0}. Also for transport aircraft aeroelastic deformation has to be taken into account when predicting aerodynamic loading although the size of the deformation is much lower. Even differences observed between theory and experiment, achieved with a steel-model in windtunnels may often be attributed to aeroelastic effects. In this area good progress has been made.

Another coupling procedure has been shown by Deslandes who combined aerodynamic prediction methods with the flight path determination. An extension of this kind of work to a large variety of stores and different release conditions at all speeds is needed.

One concluding remark on computational fluid dynamics has to be made. Since aerodynamic prediction and design methods have to be used in production design processes, especially the transonic methods must be speeded up in order to achieve realistic design cycle times. Some of the methods presented presume to have acceptable running-times but it must not be forgotten that in a real design case, these methods have to be used again and again. So a running time of more than 5 - 10 minutes for one test-case is unacceptable. This requires faster codes, but also improvements on the computer side as lower cycle time and higher storage capacities.

Perhaps someone may conclude that due to its restrictions computational fluid dynamics never will be a tool as effective as a windtunnel. Of course computational fluid dynamics never will replace the windtunnel, but a combined use of both will be the best choice for the future. As theoretical methods, also windtunnel testing still suffers from a number of shortcomings as low Reynolds number, high turbulence level, wall-interference, model-inaccuracy, aeroelastic effects etc.

3.2 Interference Aspects

Aerodynamic interference has been a key problem of this symposium. As H. Yoshihara mentioned in the Round Table Discussion, three standards of interference have to be distinguished namely adverse interference, neutral interference and favorable interference. In the past main concern of research was devoted to minimize adverse effects. Todays design generally aims to neutral interference. For the design of a wing-pylon-nacelle arrangement does this mean, that pylon and nacelle are contoured in such a way that the streamlines on the clean wing are not disturbed.

Favorable interference means, improvement of the general characteristics of a configuration by adding further parts. As example of for such kind of favorable interference H. Yoshihara mentioned the Busemann biplane, well aware that this is a supersonic problem.

Now to some specific interference problems which have been treated at this conference.

The classical problem of aerodynamic interference is that of wing and body. Classical solutions for an infinite cylinder combined with a wing in incompressible flow have been given by Lennertz and Multhopp about 50 years ago. Its worthwhile to recall the results of these rather simple theories since they provide in principle what often is shown by rather complex computer-methods. Main findings of this meeting are

- better insight in the effectiveness of fairings; avoidance of separated regions and stagnation point vortex; fairings induce a drag reduction on the wing
- the panel method has proven to be a powerful tool to design the wing-root contour and proper fairings
- the transonic methods are able to provide the global level of body interference drag although the pressure distributions are not given in the right manner.

Nevertheless there are unsolved problems

- the phenomenology of the corner flow is not fully understood
- methods for the viscous-inviscid interaction in the corner are not available
- techniques to avoid adverse effects are still restricted due to limited knowledge of the flow.

The next topic to be commented upon is the wing-strake-canard-interference. The main results are:

- The overall effects of strakes on manoeuvre performance and flight qualities are well-known and should not be further commented here. But the effects are not well-understood in their details.
- An efficient way to maintain concentrated vortex flow up to higher angles of attack and to higher c_{Lmax} is blowing parallel behind the vortex axis from the fuselage.
- As to the physical understanding some basic knowledge on vortex onset, vortex stabilization and break-down is available but not sufficient for the prediction of a complex flow-field as on a strake-wing. Here further investigations with simple configurations as delta- or swept-wings are needed. A good paper for transonic flow has been given at this conference. The occurrence of a shock-wave in the flow has been identified for low supersonic Mach number, which stabilizes an extended secondary vortex system.
- The influence of a canard on a wing with a concentrated vortex system has been shown for transonic flow. It can be seen that sudden changes in the aerodynamic characteristics occur due to different vortex break-down behaviour of the main wing.
- Theoretical methods are still restricted to subsonic flow with concentrated vortices. The onset and break-down of vortices cannot be predicted; regions with bursted vortices are beyond theoretical treatment.

Another favorable interference effect is the wing-winglet-interaction. The discussion has shown that for the improvement of existing wings, when only a small amount of additional bending moment can be admitted, winglets may be a powerful tool. The choice, whether a proper span extension or a winglet is chosen, depends on a number of parameters, some of them non-aerodynamic. The results presented at this conference are confined to two specific airplanes and do not allow general conclusions.

One of the most difficult interference problems is that of wing-pylon-nacelle-jet. The following conclusions can be drawn

- data are available which give a good insight into the influence of a jet on a wing in subsonic flow. For transonic flow as well as hot jets data are still sparse
- current status of large-scale investigations of nacelle-interference is the use of free-flown pods with devices to control the flow-through
- theoretical methods as panel methods are well suited to predict wing-pylon-nacelle interference even for cases where the nacelle is located directly on the wing. Furthermore these methods can be used to achieve neutral interference. The representation of the powered jet needs improvement, but here additional experimental information on the jet is partly available
- as to transonic flow, methods with proper incorporation of the jet are not available
- supercirculation seems to be a powerful tool to increase landing performance and manoeuvre capability at low speed.

A further topic to be mentioned is wing-store-interference. This is indeed a vast field since here a lot of favorable and adverse effects are known, some of them not understood up to now. The main findings are:

- Favorable interference has been found for some configurations by proper staggering of the stores in order to achieve a better area ruling, fixing stores at the wing-tip to get reduced lift-dependent drag, fixing the stores as close as possible to the cell (conformal carriage) to get small viscous and parasitic drag. Also special multiple store arrangements may have favorable characteristics.
- Proper fixing of stores is especially in the transonic regime a rather complicated task, since flows in corners with shocks and separation occur. Many of the effects are not well-understood up to now.
- Theoretical methods for subsonic attached flow are in current use and allow coupled with the equation of motion the evaluation of flight trajectory.
- Theoretical methods for transonic flow are still under development.

Summarizing, it can be said that interference effects should be taken into account in a design process from the beginning in order to use favorable interference effects. This is not easy at all, since in many cases basic information of physical background does not exist. Nevertheless the development of powerful computer codes provides solutions for problems which could not be tackled in the past. In contrast to this, physical insight in what is going on in the flow has not made so much progress as the computational tools. In this respect, intensive studies are necessary.

3.3 Optimization

The general problem of the overall optimization of an aircraft is a most complex problem when having in mind the different requirements and constraints. Here on one side there are specific requirements due to civil and military regulation acts. On the other side the users describe their requirements which often change from one user to the other. This is valid for civil as well as military aviation.

Main point of this meeting was the aerodynamic optimization of configurations with a look at constraints originating from other disciplines and regulations. Even this specific task is a difficult one since airplanes have to be designed for different purposes as cruise, take off, landing, loiter – flight phases which are typical for civil transport aircraft. For fighter type aircraft there are in addition a number of different manoeuvres which have to be performed with good flying qualities. This requires good performance for the subsonic, transonic and in special cases for the supersonic region, for small and high angle of attack flight, for clean and flapped configuration. Furthermore the aircraft must be stable and controllable.

It must be seen that, apart from linearized inviscid theory in subsonic and supersonic flow, all other theories for aerodynamics have a nonlinear character. This enhances the use of theoretical methods for a global optimization to a great extent. In addition it must be seen, that even if there would exist an efficient multivariate nonlinear optimization procedure, theoretical methods especially for the limits of performance – as $c_{L_{max}}$, drag-rise, buffet-onset – are still inconvenient.

So the current status of optimization is a loop in which computational fluid dynamics and windtunnel are used together to find the optimum for each design case:

- computational design and optimization
- verification by windtunnel, changes due to empirical findings or computational redesign.

In the past the windtunnel played a larger role in the whole optimization process. After some basic layout, the configuration or parts of configuration have been improved by trial and error. A major outcome of this conference is the fact that theory has become a powerful tool to develop and optimize basic and even somewhat complex configurations. Performance boundaries and arrangements of high complexity are still beyond theoretical approach.

Now looking at some special optimization problems treated at this conference. A point which has attracted much attention in the last years and which indeed has brought a considerable improvement in performance is the supercritical wing design. Here the question again and again arises, what is the optimum airfoil, a shockless or one with a tolerable shock. R.T. Whitcomb expressed in the Round Table Discussion what generally seems to be approved: "If you design a shockless airfoil, you will always get a somewhat better L/D if you increase the lift coefficient a little bit and take a little shock loss, because the gain in lift you get is greater than the increase in drag ...".

With supercritical airfoils either wing-thickness or cruise speed can be increased or wing sweep can be decreased. Looking at the increase of wing-thickness – this is the major approach – the results of this conference demonstrate that supercritical wing-technology has led up to now to an increase of wing-thickness of approximately 20%. Realizing that refined theoretical approaches are available and new techniques as sucking near the shock-location (see Krenz and Ewald (12)) are investigated, a further 20% increase or a comparable reduction of sweep at maintained cruise speed seems possible. Of course the performance boundaries will come closer to the design point.

One method for the optimization of supercritical airfoils and wings has been demonstrated at this conference. Sobieczky explained his method for designing wings with shockless pressure-distribution all over the wing. This is a fascinating tool but it has to be taken into account that there are other optimization parameters as spanwise loading, bending moment, adequate stall behaviour, construction constraints especially for the rear part etc. So a totally shockfree wing or a wing with elliptic spanwise loading must not be the optimum. More loading near the root leads to a wing with much less structural weight and less nose-down pitching-moment which may be a more favorable wing than that with spanwise elliptic loading.

So the optimum design of a wing will be a compromise where aspect ratio, planform-taper, planform details, airfoil, twist and camber are optimized with aerodynamic methods to have a supercritical design, an adequate spanwise loading, a proper distribution of the bending moment with a look at aeroelastic effects and other requirements as space for flaps, fuel volume and undercarriage. Interference effects also will play their part.

The classical interference problem is that of wing and body. Adequate wing-body performance needs the incorporation of fairings in the wing-root. Now theoretical methods allow the optimization of the root-section and the fairings as demonstrated by Voogt and v.d. Kolk (25). In another paper the classical way of experimental testing by trial and error in windtunnel is shown (Jupp (11)). In this procedure special care has been devoted to the vortex originating from the stagnation point in the wing-root.

Another important means to optimize a wing is the attachment of winglets. The paper by Rettie (27) has proven that a theoretical optimization of such devices is feasable for subcritical flow, which holds in the supercritical region. Improvements achieved for two specific configurations are approximately 6% in L/D. This has been achieved improving existing wings.

The aerodynamic performance of wings for combat aircraft can be improved by addition of strakes, manoeuvre-flap or even variable camber, spanwise or chordwise blowing. As to strakes it is well known that a strake may lead to considerable improvements of performance and handling qualities. Manoeuvre-flaps resp. variable camber may give an improvement in manoeuvre performance with gains in wing-area and with it weight. Another quite interesting concept seems to be the forward swept wing which could have a superior aerodynamic performance provided the adverse aeroelastic divergence can be overcome and some aerodynamic problems solved. Furthermore it has been shown that quite simple blowing concepts lead to considerable performance improvements especially at low speed manoeuvre flight and for landing. All these solutions and proposals are results from experimental parametric studies or experimental trial and error optimizations.

Optimization of engine integration also is an important task. In this area too, it has been shown that the use of theoretical methods can be used with success although the finding of the real optimum including favorable interference is at least a trial and error procedure. Perhaps the most realistic way to find aerodynamic optimal performance for a complex configuration is to look into the wake as J.E. Hackett pointed out in the Round Table Discussion. Munk sixty years ago has given a comprehensive account of optimal wakes for planar and nonplanar wing-arrangements. A reexamination of his results will lead to conclusions where unfavorable and favorable interference will occur. But its also necessary to look after other effects in the wake as the axial velocity defects due to viscous drag and shocks and higher axial velocities as jet effects. What's the optimal distribution of the perturbation?

Aerodynamic optimization of airplanes is not only development of new methods and improved windtunnel techniques to get better performance for conventional aircraft. New ideas and new techniques have to be explored. Some have been discussed at this meeting as canard configurations, forward swept wing, spanwise and chordwise blowing, overwing engine and winglet.

Prospects of the future of aviation show that boundary-layer control, transonic propeller, span-loading concepts, post-stall flight etc. may lead to considerable improvements of performance. None of these concepts has been discussed although these techniques may have a large impact on the performance of aircraft.

3.4 Some Additional General Remarks

This technical meeting has provided a considerable insight into computer fluid dynamics for aircraft configurations, multiple interference effects and configuration optimization. Nevertheless some critical remarks have to be made:

- The treatment of the viscous flow played a rather small roll in this symposium.
- The impetus to understand and to explain the physical background responsible for many effects in the flow has been small.
- Some presentations have been mere agglomerations of a large number of results comprising various problems sometimes without interpretation of the significance of them.
- The number of figures often exceeded thirty for an allotted twenty minutes presentation. It should be taken into account that twelve slides are sufficient, so that there is time enough to explain each figure in a sufficient way.

4. RECOMMENDATIONS

Subsonic/transonic configuration aerodynamics comprise such a large amount of different topics that necessarily fields can be seen where much progress is going on, others where there is a stagnation. Some points can be identified where review or support in some form should be appropriate. Therefore it is recommended to

- arrange a symposium on "Computational Fluid Dynamics". We have seen a fast development of a large number of different methods, so that a comprehensive account of the state of the art seems to be necessary. Perhaps this should be combined with a concurrence calculation for some datum examples. In any case such a meeting should be devoted especially to modelling and mathematics,
- arrange a symposium on "Phenomenology in Fluid Dynamics". Here problems of vortex onset, vortex formation, vortex burst, shock-boundary-layer-interaction, trailing edge flow, stability of free shear layers, jet properties, separation topology should be presented. Basic insight in flow phenomena is necessary for a proper modelling of flow fields for theoretical evaluation. More experimental information must be given to the theoreticians,
- establish a working group or advise an aerodynamicist to collect, categorize and evaluate models for separated flow. Separated flow seems to be a most demanding task for the future. A comprehensive evaluation of the present knowledge would be helpful for future research efforts.

5. REFERENCES

1. Mercer, J.E.; and Murman, E.M.: Application of transonic potential calculations to aircraft and wind tunnel configurations.

2. Vigneron, Y.; Brocard, O.; Bousquet, J.; et Lejal, T.: Une méthode variationnelle d'éléments finis pour la résolution d'écoulements transsoniques tridimensionnels.

3. Heckmann, G.: Etude par la méthode des éléments finis des interactions voilure-fuselage-nacelle pour un avion du style Falcon à Mach = 0,79.

4. Bore, C.L.: Increasing the value of airforces by improving external store configuration.

5. Haines, A.B.: Prospects for exploiting favourable and minimising adverse aerodynamic interference in external store installations.

6. Deslandes, R.: Evaluation of aircraft interference effects on external stores at subsonic and transonic speeds.

7. *)

8. Stahara, S.S.: Study of transonic flow fields about aircraft: Application to external stores.

9. Schmidt, W.: Aerodynamic subsonic/transonic aircraft design studies by numerical methods.

10. Sobieczky, H.: Design of advanced technology airfoils and wings.

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29. Anders, G.; Giacchetto, A.; and Gravelle, A.: Philosophy and results of steady and unsteady test techniques on a large scale transport aircraft model in the ONERA transonic tunnel S1 MA.

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14. Abstract

This report presents an evaluation of the presentations made and the discussion held during the AGARD Fluid Dynamics Panel Symposium on Subsonic/Transonic Configuration Aerodynamics held 5–7 May 1980 in Neubiberg, Federal Republic of Germany. A brief discussion of the presentations is followed by a summary of conclusions and recommendations for action. The full text of the papers presented at the Symposium is available in AGARD Conference Proceedings No.291, published in September 1980. This report was prepared at the request of the Fluid Dynamics Panel of AGARD.

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